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$$N2 = \cos^2 2\alpha_T \quad (17)$$

$$N3 = (\rho c / \rho_L c_L) (Con^2 - 1)^{0.5} / \cos \alpha \quad (18)$$

For an incident angle of 45°, the term for N2 is equal to 0 and the reflection coefficient reduces to

$$R_{tt} = (N1 - N3) / (N1 + N3) \quad (19)$$

One objective is to show that the density and velocity of sound can be obtained from RC₉₀ and RC₄₅. The above equations show that this is possible. In Eq. (16) for N1, all of the quantities are known and so N1 can be evaluated numerically. In Eq (18) for N3, there are two unknown terms: ρc and $\cos \alpha$, where α is the angle of the transmitted beam in the liquid. Solving Eq (19) for N3 and using the symbol RC45 for R_{tt}, we find the following:

$$N3 = N1(1 - RC45) / (1 + RC45) \quad (20)$$

Therefore, N3 can be evaluated since values have been obtained for both N1 and RC45.

In Eq (18) for N3, there are two unknown terms: ρc and $\cos \alpha$, where α is the angle of the transmitted beam in the liquid. However, the acoustic impedance of the liquid ρc is known from Eq (13). Thus, Eq. (18) can be solved for $\cos \alpha$ and, of course, the angle α can also be determined. The velocity of sound can be determined from Snell's law of refraction, as follows:

$$\sin \alpha_T / \sin \alpha = c_T / c \quad (21)$$

Since the angle α has been determined, the only unknown in Eq. (21) is the velocity of sound in the liquid, c . Thus, the velocity of sound can be determined. The density can be determined from the value of the acoustic impedance of the liquid, Z_{liq}.

$$\text{Density of liquid } \rho = Z_{liq} / c \quad (22)$$

The use of the perpendicular measurement of multiple reflections and the self-calibrating feature of these measurements has been documented in U.S. Pat. No. 6,763,698, in which an accurate value of the acoustic impedance of the liquid is obtained. In this technique, the velocity of sound is obtained by measuring the passage of ultrasound through the liquid or slurry. The present invention omits the measurement through the liquid or slurry and instead utilizes the measurement of the SV shear reflection coefficient for incidence at an angle to a solid-liquid interface. The experimental data focuses on the data obtained for incidence at a 45° angle at a solid-liquid interface. The material for the 45° triangular wedge was chosen to be stainless steel, which leads to a more difficult measurement than using fused quartz. Fused quartz results in many echoes.

The measurements were performed using a stainless steel (SS304) triangular wedge as shown in FIG. 4. The base of the triangular wedge was immersed in various concentrations of sugar water, for which the density and velocity of sound were measured directly utilizing traditional methods, and then again utilizing the presently described methods. The objective was to show that the experimental measurement of the reflection coefficient is in agreement with the calculations of the reflection coefficient for an incidence of 45°, using known values for the density and velocity of sound in sugar water solutions.

FIG. 4 the base of the triangle is 1.5 inches and the angles at the base are 45°. A commercial shear wave transducer having a diameter of 0.5 inches and a frequency of 1 MHz was coupled to the unit using shear-wave coupling gel. The shear wave transducer was mounted so as to produce vibrations that create shear vertical waves (ST). A pulse of ultrasound is

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reflected twice at the solid-liquid interface during each roundtrip. As many as five echoes can be observed by the transducer, as shown in FIG. 5. The advantage of using a 45° angle is that no reflected longitudinal wave in steel can be produced (as discussed previously), while at a smaller angle—say, 20°—a reflected longitudinal wave is produced. Thus, when the incident shear wave strikes the steel-liquid interface only two waves result: 1) the reflected shear wave and 2) the longitudinal wave transmitted into the liquid. As a result, the reflected shear wave has sufficient energy to produce echoes.

An expanded view of one echo is shown in FIG. 6 and the fast Fourier transform of that signal is shown in FIG. 7. The usual treatment is to take the maximum FFT amplitude for a liquid (or slurry) and compare it with the maximum FFT amplitude for water. The original derivation has been extended to include the amplitude at several frequencies, as this has been discussed and the derivation carried out in Eq. (6) through Eq. (10).

FIG. 8 shows the data obtained for the five echoes for 50% sugar water, using the extended method to obtain the FFT amplitude, as described in Eq. (10). For the sake of simplicity, this is referred to as the PFT amplitude. A similar calculation was obtained for the FFT amplitude for water for five echoes. For each echo, the HT amplitude for a liquid was divided by that for water and the natural logarithm of that quantity was obtained. In FIG. 8 the ordinate is the following: Log (FFT amplitude for liquid for echo N / FFT amplitude for water for echo N), while the abscissa is the echo number N. As described earlier, the reflection coefficient is related to the slope of the line. Similar calculations and graphs were obtained for each liquid.

Because two reflections occur in each round trip, Eq. (5), is modified by including, a factor of 2.

$$R_{Clig} / R_{Cwtr} = e^{slope/2} \quad (23)$$

The experimental value of R_{Clig}/R_{Cwtr} was determined using Eq. 23 by finding the slope of the line, similar to that in FIG. 8 for 50% sugar water. The experimental values of the ratio R_{Clig}/R_{Cwtr} for six sugar water solutions are plotted versus the sugar water concentration in FIG. 9 using a diamond shape and the theoretical values of the ratio R_{Clig}/R_{Cwtr} by squares.

The theoretical calculation was carried out using Eq. (19), for water and the six sugar water solutions. In each case, the density of the solution and the velocity of sound in the solution were measured independently by standard techniques. The velocity of sound was obtained by measuring the time-of-flight through the liquid and the density was obtained by weighing a known volume of a sugar water solution. These values were then used in the theoretical formulae in Eq. (14), through Eq. (21), to obtain the reflection coefficient for water and the reflection coefficient for each sugar water solution. For each sugar water solution, the ratio R_{Clig}/R_{Cwtr} were obtained and plotted in FIG. 9. The comparison between the experimental and theoretical values in FIG. 9 shows very good agreement.

In a preferred form, the speed of sound in the fluid (c) is determined by performance of multiple reflections of a shear wave at a non-perpendicular, preferably a 45 degree angle of incidence at the solid-liquid interface. Preferably this is performed utilizing a fused quartz window in a pipeline and a 45-degree quartz triangular wedge in contact with the slurry. Because fused quartz has a smaller acoustic impedance (density × velocity of sound) than stainless steel, this design permits very high accuracy in the density measurement because the reflection coefficient for fused quartz is smaller than that